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PROCEDURES FOR COLLECTION OF RELIABILITY, AVAILABILITY, AND MAI--ETC(U)
JAN 79 E M TAKEMORI, M J POLLOCK

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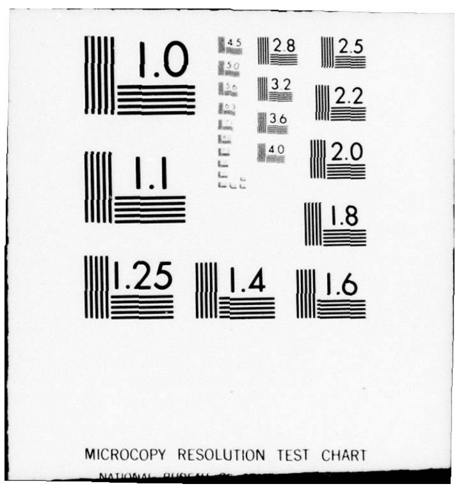
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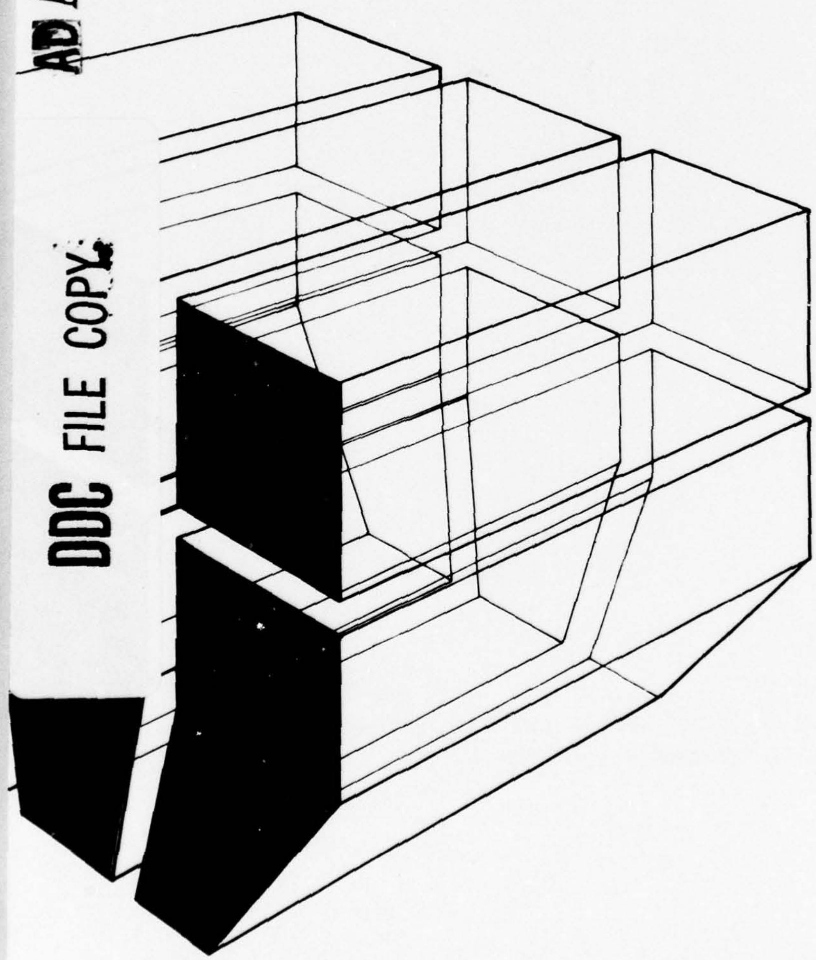
construction engineering research laboratory

SPECIAL REPORT E-137
January 1979
Reliability, Availability, Maintainability for Electrical and Mechanical Systems

PROCEDURES FOR COLLECTION OF RELIABILITY, AVAILABILITY, AND MAINTAINABILITY DATA ON ELECTRICAL AND MECHANICAL SYSTEMS



by
E. M. Takemori
M. J. Pollock

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This report presents the results of a study of methods to acquire and store data on the reliability, availability, and maintainability (RAM) of electrical and mechanical systems. Data acquisition methods previously used by the Corps of Engineers were reviewed and new methods and equipment now being developed were evaluated. Forms are proposed to aid in the collection and handling of information in a logical manner. Methods for storing data either manually or by computer are also presented. → next page

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cont. The results show that new computer systems, together with available communications equipment and the proposed forms, can be combined to provide an efficient and economical means of acquiring and storing RAM data.

FOREWORD

This study was performed for the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under Project 4A763734DT08, "Construction and Field Engineering Development"; Task 07, "Power Systems"; Work Unit 003, "Reliability, Availability, Maintainability for Electrical and Mechanical Systems." The applicable QCR is 3.07.021. The OCE Technical Monitor was Mr. J. P. Ferratt, DAEN-MPE-E.

This investigation was performed by the Energy and Habitability Division (EH), U.S. Army Construction Engineering Research Laboratory (CERL). CERL personnel directly involved in the study were M. Gazda, T. L. Stoner, and E. M. Takemori. The efforts of G. C. Rettberg in reorganizing and rewriting a portion of this report were of great value.

Mr. R. G. Donaghy is Chief of EH. COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

TABLES

FIGURES

PROCEDURES FOR COLLECTION OF RELIABILITY, AVAILABILITY, AND MAINTAINABILITY DATA ON ELECTRICAL AND MECHANICAL SYSTEMS

1 INTRODUCTION

Background

Generally, the Corps of Engineers builds facilities and releases them to a user; however, there is rarely a return of information on such critical aspects as operation and maintenance (O&M) experience, failure frequencies, recorded lifetime, replacement rates, wear rates, performance experience, or other indications of a facility's quality or effectiveness. District Engineer personnel need information on which to base reliability, availability, and maintainability (RAM) estimates for electrical and mechanical equipment and systems (EMS). This information and the calculated RAM estimates are required to improve future selection of equipment and systems specified for use in military construction Army (MCA) projects.

Data acquisition is a long lead-time item. Experience on past projects has demonstrated that procedures required to translate and reduce RAM and EMS data have been the most costly and time-consuming operations of the total data acquisition-reduction-processing-analysis function. However, during the R&D studies on the SAFEGUARD System,[1] considerable failure and repair data were accumulated on engine-generator sets and on related power plant equipment. The data contributed significantly to important reliability estimates and logistics and manpower planning.

Data to be collected for analyzing RAM falls into three categories: (1) historical data, (2) present data, and (3) future data.

Historical data is available now; it is recorded manually, usually on sets of forms, each of which is designed to provide operation and maintenance (O&M) personnel with information about their duties. Frequently, individual manual systems have been developed and used to control, manage, and schedule separate maintenance operations. Normally, reports on operations must be prepared periodically (usually monthly)

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[1] Booz, Allen, Applied Research, Inc., Data Systems Procedures, AD871151L (Department of the Army, May 1970).

for management review and assessment; however, with the current data recording method, the costs of spare parts and supplies may not be segregated for accounting purposes in a fashion that is amenable to analysis.

Present data uses the same collection methods as historical data.

Future data is data that will be available and for which better collection systems should be developed.

Within the Army, the information which provides the needed data is obtained by the Facility Engineer; however, the reports currently required to record this data are not detailed enough to provide sufficient information for a RAM analysis. Redirection and expansion of the reporting procedures are necessary to assure provision of adequate data in the future.

Military facilities are becoming increasingly dependent on EMS for accomplishing their assigned mission tasks; as a result, the RAM factors associated with EMS and their components have become equally important. RAM factors indicate that assigned EMS tasks can be accomplished within the specified mission time under specified environmental conditions without failure, and without injury to operating personnel. These requirements have become especially important for EMS involved in hazard- or risk-type missions, i.e., electrical systems, lighting systems, equipment-handling systems, transportation systems, and chemical-handling systems.[2]

Problem Statement

There is a need for an orderly process of obtaining and using field experience information to improve the quality and to facilitate the design of military facilities. A cost-effective means of acquiring RAM data for EMS in military installations is essential to improve a facility's ability to function as designed, and therefore its performance. Fulfilling this requirement will provide District Engineer personnel with operating experience data on the frequency of normal maintenance, repair, and replacements of facility components. This capability can be used to improve future designs for military facilities, particularly those having specific RAM requirements. The anticipated data will enable effective selection of facility components.

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[2] Booz, Allen Applied Research, Inc., Data Systems Procedures, AD871151L (Department of the Army, May 1970).

The Facility Engineer also needs RAM information to provide a firm basis for budgeting electrical/mechanical equipment maintenance and to schedule manpower, equipment, and overhaul and replacement requirements. Adequate data will permit knowledgeable decisions regarding system availability-reliability estimates, maintenance policies, and manpower requirements.

Objective

The objective of this work was to develop methods for acquiring and storing information necessary for making RAM assessments or estimates of EMS for military facilities.

Approach

The following work was conducted to accomplish this objective:

1. Review current analytical techniques used to assess RAM and life cycle cost (LCC) factors, electrical and mechanical systems, and equipment to identify required data types.

2. Determine system types and equipment installations involved in military facilities and evaluate these to ascertain if any or all are critical to facility operations.

3. Identify data types available from historical records to provide direction for developing manual data collection methods.

4. Evaluate current data-recording methods used on existing systems and equipment installations within fixed military installations to develop a data-acquisition system.

5. Identify current data sources which may be used for assessing EMS to provide a ready source of data, and to provide guidance in developing a new EMS-RAM data bank which can be accessed either manually or mechanically.

6. Evaluate the requirements for making a totally manual, statistically supported RAM data base; compare this method with the Data Procedure methodology developed by Booz, Allen Applied Research, Inc. (BAARINC) for OCE to establish a confidence level for the manual method.

7. Develop a manual method which would not use preformatted, machine-readable forms.

8. Prepare machine-readable, preformatted forms to be used for source-data acquisition of RAM-type data and which would be compatible with manual methods.

9. Develop data analysis techniques which would be used to convert raw RAM and LCC data to statistically analyzed data by either manual and/or machine-aided processes.

10. Determine the best method for storing and retrieving statistically analyzed RAM and LCC data by either manual or mechanical processes.

11. Recommend the best manual and/or mechanical procedure for making EMS-RAM assessment.

Outline of Report

Chapter 2 presents the type of data identified as necessary for making RAM evaluations, and Chapter 3 provides the data sources and the value and limitations of these sources. Chapter 4 outlines the methods of data collection which were evaluated and discusses their use for obtaining historical and present data. Chapter 5 outlines and evaluates future data collection methods; Chapter 6 recommends the methods thought to be most feasible to provide the most usable, accurate data and estimates the cost of the recommended system. Chapter 7 outlines the advantages of using an automated system, and Chapter 8 discusses the equipment needed for such a system. Chapter 9 defines manpower requirements for an automated system; Chapter 10 outlines a recommended data bank organization and defines the central clearinghouse operation.

Methods of analyzing data are not presented here; however, Appendix A lists references for analytical techniques. Appendix B presents form samples.

Mode of Technology Transfer

This report constitutes the technology transfer for this work.

2 TYPES OF DATA REQUIRED

The data required to determine RAM factors for EMS include the chronological history of operation, failure events, and preventive and restoration maintenance events. The RAM factors of EMS and their components are not readily available to District design engineering personnel for preparing the technical provision for EMS procurement specifications.

The construction activities of Army-wide military facilities were reviewed to identify those risk- or hazard-oriented activities which involve the use of EMS and their components. Lists of components have been prepared which are hazard- or risk-oriented, and this data will be required for assessing the RAM and LCC of EMS.

This review indicated that the critical systems are:

1. Power generation
2. Electrical distribution
3. Lighting
4. Heating boilers
5. Chillers
6. Air-handling equipment
7. Controls
8. Water treatment
9. Fuel supply.

The list of hazardous systems for RAM assessment input was presented in a previous CERL report.[3] This data list is provided for all 14 systems listed in that report without regard to priority or to exclusions of systems such as sewage, firefighting, and communications.

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[3] E. M. Takemori, Mission Critical Electrical-Mechanical Systems in Military-Constructed Facilities, Unpublished Report C-23 (CERL, January 1975).

3 AVAILABLE SOURCES OF DATA

Available RAM data sources include military and industrial records from operating EMS, and manufacturers' specifications. Appendix A contains a list of data sources. Since the information required is not all numerical and much of it is handwritten, it may be difficult to identify and chronologically classify failure and maintenance events.

Military records are confined to a 2-year period, which limits the data's validity. The number of failures, maintenance actions, and overhaul times during that period may be insufficient to provide valid information. For instance, where failures and maintenance actions occurred over a 3-year period, but the data for the third year is not available, the information is incomplete, and confidence in the use of such data may be reduced.

Procedures developed for acquiring available data include obtaining information from EMS manufacturers, i.e., obtaining the names and locations of civilian users. Questionnaires have been developed for obtaining other information from the manufacturer, including characteristics of the equipment and maintenance information. The same approach has been developed for obtaining data from industrial installations.

Records from the Finance and Accounting Office are available; however, this information would be useful mostly for checking parts inventory and for indicating a component's frequency of repair and the time required to repair it. Since this information is mostly for replacement parts, it does not provide significant information for RAM analysis.

4 DATA-COLLECTION METHODS (HISTORICAL AND PRESENT)

The method expected to be used for data retrieval and analysis determines what methods will be developed for collecting historical and present data. In most cases, the format for recording the data is not suitable for rapid collection. Getting data into a recordable format would require revising the operating forms containing the chronological order of events and load profiles. It would also necessitate combining an operating form with a maintenance form to reduce the number of documents handled and to enable chronological arrangement of the failure and maintenance activities.

Past methods of source data collection that were useful for design, RAM, and LCC analysis have been dictated primarily by operational and facility management considerations. The procedures usually employed to correlate the many and diverse data elements necessary for comparative design analysis, and for RAM and LCC analysis, have been found to be costly, time-consuming, and nonresponsive to the usual time-frame allowable for District operations. For example, some types of data collection require high manpower and experience levels for retrieval and analysis. Studies have shown that there is a high degree of commonality between the data elements necessary for RAM analysis and those for LCC analysis. The technique of any proposed data-collection method should be able to improve and/or reduce the data-recording efforts of facility operational personnel.

New Data-Collection Methods

Several areas of investigation have been pursued to facilitate data collection:

1. Developing a single set of data elements that are ordered in a fixed format.

2. Developing a method(s) of source data recording and entry which (1) is compatible with the types of environments involved; (2) will provide hard copies of data entered for operational usage; and (3) will provide means for automatically (machine) generating the data element set developed in Method No. 1 (explained above).

3. Achieving the capability of adapting the combination of methods and data element sets for performing the required analysis so that (1) the labor and time required for analyzing historical records are reduced; and (2) present facility maintenance recordkeeping procedures are observed.

4. Achieving compatibility with operational practices and designs for future automated power plants and EMS systems. Extensively used variations of this technique are (1) microfilming, (2) combining and ordering onsite operational records, (3) manually extracting the pertinent data elements, and (4) placing these data elements in the required data format for analysis. The cost of this technique was determined to be 60 cents per frame.

This investigation has completed a consolidated set of data elements and revised, for RAM analysis, the data format of Office of the Chief of Engineers (OCE) Form I to include:

1. Diagnosed reliability factor
2. Confidence level
3. Performance requirement
4. Stress levels.

The data elements in OCE Form II have been reorganized into the categories of:

1. Card collation data
2. Event collation data
3. Repair statistical data
4. Operating cost data.

The revised Forms I and II have been given the acronym "CRAM" to reflect the incorporation of the necessary data elements to provide for RAM and LCC analysis (see Figures 1, 2, and 3). Form II data records cannot be completed on the basis of single, complete entries, since the source data will come from maintenance logs, monthly summary reports, time cards, fuel consumption meters, and accounting records. Instead, they require multiple entries, based on raw data from different sources at different times. It is therefore necessary to build into the source-data collection method an ability to enter such discrete segments of data and to categorize such segments automatically. To facilitate the record search and updating operations, columns 1 through 19 (Form II, Figure 3) have been allocated as various identifiers which would be common to all Form II program cards associated with a specific equipment item. The remaining 61 columns are used for the individual data elements.

The development of methods for source-data collection and recording recognizes that the major prerequisites for a successful overall approach are the provisions for greater flexibility, response to varying environmental conditions, and to the needs of operational personnel. Several more efficient techniques have been developed for recording data in various operational environments at their sources.

DATA ELEMENT TYPES

WHO PRES	WHO SUG.	WHY (USED FOR)	HOW OBTAINED	WHAT PURPOSE	WHERE ENTER	WHERE USED	WHEN ENTER	WHEN USED	DESCRIPTION	COL'S	CARD TYPES
									① CARD COLLATION DATA		
NEW	P/P	ID CARD TYPE	CERL GUIDE CODE	CORRELATION	P/P	DATA BASE	P/P	DATA BASE	Ⓐ CARD ID CODE	(1)	2A,B
—	P/P	BASE LOG	P/P CERL LISTING	CORRELATION	P/P	DATA BASE	P/P	DATA BASE	Ⓑ BASE ID	(2)	2A,B
—	P/P	FACIL ID	P/P CERL LISTING	CORRELATION	P/P	DATA BASE	P/P	DATA BASE	Ⓒ FACILITY ID	(3)	2A,B
MF	MF	RECORD OF WORK	ASSIGNED BY MF	TIE ALL ACTIONS PER EVENT	MF	POAR DATA BASE	START EVENT	POAR ANAL	Ⓓ WORK ORDER NO.	(5)	2A,B
MM/MF	MM/MF P/P	EQUIPMENT RECORDS	TAG NO/ GUIDE CODE	DATA CORREL FOR ANAL	SHOP P/P	POAR DATA BASE	START EVENT	POAR ANAL	Ⓔ EQUIPMENT ID	(3)	2A,B
									② EVENT COLLATION DATA		
←			SAME AS ⒹD ABOVE					→	Ⓐ WORK ORDER NO (PER ID ABOVE)		
MM/MF	MM/MF	DATE RECORD	—	DATE TIE-IN	SHOP	POAR DATA BASE	START EVENT	POAR ANAL	Ⓑ DATE CODE	(6)	2A,B
MM/MF	MM/MF	TIME RECORD	—	TIME OF DAY	SHOP	POAR DATA BASE	START EVENT	POAR ANAL	Ⓒ TIME OF DAY	(4)	2A,B
MM/MF	MM/MF AVAIL	EQUIPMENT ERT	—	TOTAL EQPT OPERATING HRS	SHOP	POAR DATA BASE	NORM LOG EVENT	POAR ANAL	Ⓓ ELAPSED RUNNING TIME	(6)	2A
NEW	MM/MF IF CLOCK	AVAIL CALC.	PRES REL ANAL PROP BY CLOCK	SIMPLIFY DATA REDUCTION	NOT DONE	DATA BASE	START EVENT	ANAL	Ⓔ AVAIL CLOCK READING	(6)	2A
MM/MF	MF	IDENT TYPE OF ACTION	DECISION (ON FORM)	EVENT CLASSIFICATION	SHOP	POAR DATA BASE	START EVENT	POAR ANAL	Ⓕ EVENT TYPE (FOAMIXSD)	(1)	2A
MM/MF	MF	IDENT CAUSATIVE FACTORS	DECISION (ON FORM)	EVENT CLASSIFICATION	SHOP	POAR DATA BASE	START EVENT	POAR ANAL	Ⓖ ERROR TYPE	(1)	2A
MF	MF	IDENT TYPE OF ACTION	DECISION (Y/N) (ON FORM)	EVENT CLASSIFICATION	SHOP	POAR DATA BASE	START EVENT	POAR ANAL	Ⓗ SCHEDULED	(1)	2A
MM	MM/MF	INDICATION OF DIAG TECH	DETECTION MEANS	EFFECTIVITY OF DET MEANS	SHOP	POAR —	START EVENT	—	Ⓘ INDICATION NOTE ④	(1)	2A
MF	MF	SYSTEM LEVEL CLASSIFICATION	DECISION CERL GUIDE CODE	RELA OF EQPT WITHIN SYS(S)	SHOP	DATE BASE	START EVENT	ANAL	Ⓙ INDENTURE LEVEL	(9)	2A
MF	MF	EFFECT ON MISSION AVAIL	DECISION (ON FORM)	RELA OF EVENT ON MISSION	SHOP	DATA BASE	START EVENT	ANAL	Ⓚ EFFECT	(4)	2A

NOTES
① P/P - PREPRINTED
② MM/MF - MAINTENANCE MAN/FOREMAN
③ POAR - PLANT OPERATIONS AND REPORTS
④ MAY BE USEFUL FOR DESIGN, N/F DATA ANALYSIS
⑤ INFO NOT USUALLY AVAIL. DEPENDENT ON MAINT POLICY JUDGEMENT REQ TO ADJUDICATE TOTALS TO SPECIFIC EVENTS
⑥ PARTS COST SHOULD BE COMPILED AS WORK PROGRESSES; ONLY TOTAL IS ENTERED, UNLESS FAILURE ANALYSES ARE FORECASTED

Figure 1. CRAM Data Form II Element Type Analysis, Part 1 (card collation and event collation).

DATA ELEMENT TYPES			WHO		WHY	HOW	WHAT	WHERE		WHEN	
③ REPAIR STATIST. DATA DESCRIPTION	COL'S	CARD TYPES	PRES.	SUG	(USED FOR)	OBTAINED	PURPOSE	ENT.	USED	ENT.	USED
Ⓐ % FULL LOAD / PEAK LOAD	(3)	2A	OP. LOG DISP LOG	SAME, USE SYS	PLANT OPERA HIST.	MAN ENT.-FORM MACH. CORREL	PLANT OP. HIST. FAILURE CAUSE	OP LOG AT MACH DISP LOG-CONFIRM		HRLY	POAR ANAL
Ⓑ CORRECTION LOC	(1)	2B	MM/MF	MF	DET. WHERE COR. PERFORMED TAG FOR FOL-UP	DECISION (ON FORM)	TAG FOR FOLLOW-UP FOR ADDL. DATA	SHOP	POAR DATA BASE	COMPL. EVENT	POAR RETR. ANAL
Ⓒ PARTS USED (Y/N)	(1)	2B	MM/MF	MM/MF	TAG FOR FOLLOW-UP	DECISION (ON FORM)		SHOP	POAR DATA BASE		
Ⓓ PARTS COSTS	(7)	2B	NEW MM/MF (COMMENTS)	MM/MF		INFO. SOURCES PROC. INV. SUPP SEE NOTE 5	COST OF PARTS FOR REPAIR			SEE NOTE 6	
Ⓔ TIME TO RESTORE	(2)	2B	NOT USUALLY DET PER SE MM/MF	MM/MF	CALC TTR	INFO SOUR. MAINT LOG TIME CARDS, W/O FORMS, CLOCKS, ETC	TTR REQ FOR R/A	SEE HOW	POAR DATA BASE	AFTER COMPL. EVENT	POAR RETR ANAL
DIAGNOSIS	(4)										
LOGISTICS	(5)										
CHECK-OUT	(2)										
TOTAL TO RESTORATION	(5)										
Ⓕ ADMIN. DOWN-TIME	(5)	2B			CALC TTR AND AVAIL	LOGS COMMENTS	TTR AND AVAIL		DATA BASE		
Ⓖ LABOR											
SKILLED	(5)	2B	MM/MF	MM/MF	CALC LABOR CONTENT OF REPAIR COSTS	MAINT LOG TIME CARDS W/O FORMS	CALC LABOR CMBS	W/O FORMS TIME CARDS DEPOT & SUPPLY PROC		AFTER COMPL. EVENT RETURN OF REPAIR COMPON	POAR RETR ANAL
UNSKILLED	(5)		MM/MF	MM/MF							
SKILLED OFF-SITE	(5)		DEPOT OR CONTR	MF							
④ OPERATING COSTS											
Ⓐ MANPOWER		2C	NOT DEFINED TO DATE								
Ⓑ FUEL											
Ⓒ LUBE OIL											
Ⓓ SUPPLIES ETC											

Figure 2. CRAM Data Form II Element Type Analysis, Part 2 (repair statistical data and operating costs).

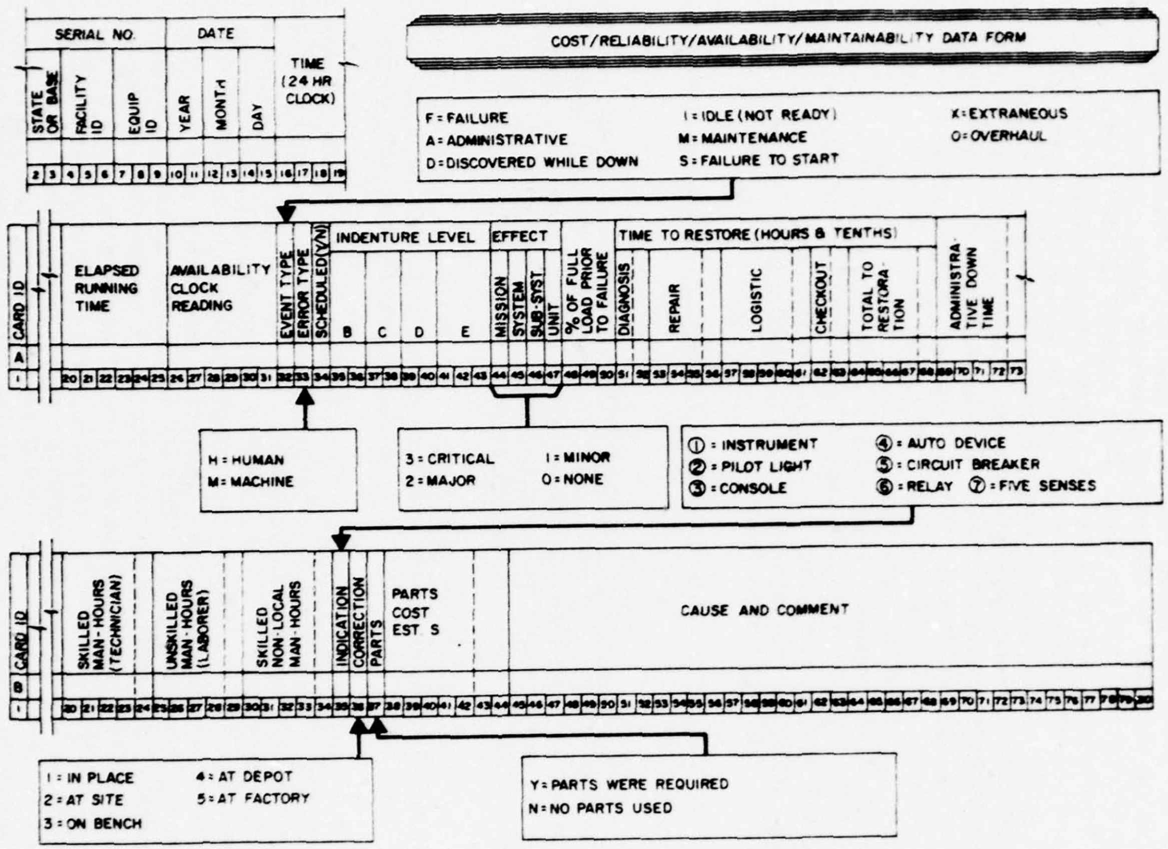

Figure 3. CRAM Data Form II.

Data Recording

To record the meter readings required for load-profile data in the operating room and in the engine-generator plant, a digital cassette type of recorder can be used. Data entered in such a digital recorder can be re-entered into a memory system automatically. To record data at a maintenance dispatching area, neither an audio cassette or a manual data entry can be used; a console operator transcribes such data. To record data at more external sources, either manual entry or audio cassette techniques can be used. The objective is to eventually replace manual entry techniques entirely; however, during transitional periods, the methods now being used will be accommodated with this type of approach. Translating such recorded data to hard copy, and simultaneously entering it permanently into a machine-readable format will be effected by a relatively inexpensive type of minicomputer information process or terminal apparatus having flexible input and output capabilities. Estimating costs for collecting historical and present data will probably be 25 to 40 cents per data frame.

The available data-collection methods which were experimentally verified are:

1. Manual entry on forms. This method must be compatible with system operation. The operating personnel must be able to maintain present data recording and presentation methods to insure smooth transitions between present and newer methods; this capability must be provided so the overall system can be used on historic records.

2. Audio cassette recorders. This method is used in environments where noise considerations are not controlling; its use must be combined with data formats, so that data elements are entered in correct order.

3. Punched card method. This technique is used to collect data in such field environments as external electrical distribution systems. The punch-card method can be used to collect EMS data to build a data base for assessing RAM. The card is prepunched with the equipment ID number, facility ID number, and system number. If a failure is noted on the system or equipment, the respective prepunched card is selected (if weather conditions permit, the card is located at the site and on the equipment), and the desired information is handwritten on the preformatted card (such as date and time of occurrence, type of failure as denoted by BAARINC, and if available, present-hour meter reading). Then the card is keypunched for computer application. The problem with this method is that if there are 1000 different items, there will have to be 1000 different prepunched cards at the site. The BAARINC method uses a minimum of two cards for each item to satisfy total RAM input data.

4. Digital cassette recorder. This technique is useful in noisy environments and is designed to be used with the forms normally used in data collection; the data elements are keypunched in the correct order. The proposed recorder presents a visual display of the data for checking purposes before it is entered on the cassette. A major advantage of this technique is that after the operator places the correct permanent tape in the console, the information on the digital recorder cassette can be entered automatically as a permanent record without transcription by the operator.

5. Dual removable disk drive unit. The dual removable disk drive unit, or a disk file, uses a flat disk for storing digital information. It uses an electromagnetic storage medium and heads that operate similarly to tape recorder and playback heads. This method is probably better than using cassette tapes because there is more storage capacity and the disks have greater random-access capability. This method reduces the time required to provide a hard-copy report from 15 to 30 minutes to 3 to 5 minutes. In addition, the operator will not have to change the storage file as frequently.

6. Digital modem recorder. A digital modem recorder or modulator/demodulator accepts signals and modulates or impresses the information on a carrier signal. At the other end of the circuit, it reverses the process that recovers the information. This technique is useful for noisy environments where large numbers of data elements must be transmitted to a more permanent recordkeeping facility. Its operation is similar to that described for the *digital cassette recorder*, except that the digital modem is patched directly into the console with a telephone line, and the data elements are entered directly into the console permanent record tape.

Organization of a Minicomputer System

Many minicomputer systems have been developed which can be purchased at prices ranging from approximately $6000 to $9000, depending on the individual capabilities and provisions desired. Figure 4 illustrates a system for collecting historical and present data.

The Wang System 2200 has been used experimentally in the field. Communications among as many as two to four such systems can be accommodated at one location, using telephone lines and modems. It is also possible for one installation having this system to communicate with a remote location. This type of communications system could be used in situations like that of the hospital and the Facility Engineer Office at Fort Hood, TX. The system 2200 consists of a console; a combining and interactive display screen (CRT); a normal typewriter keyboard that is

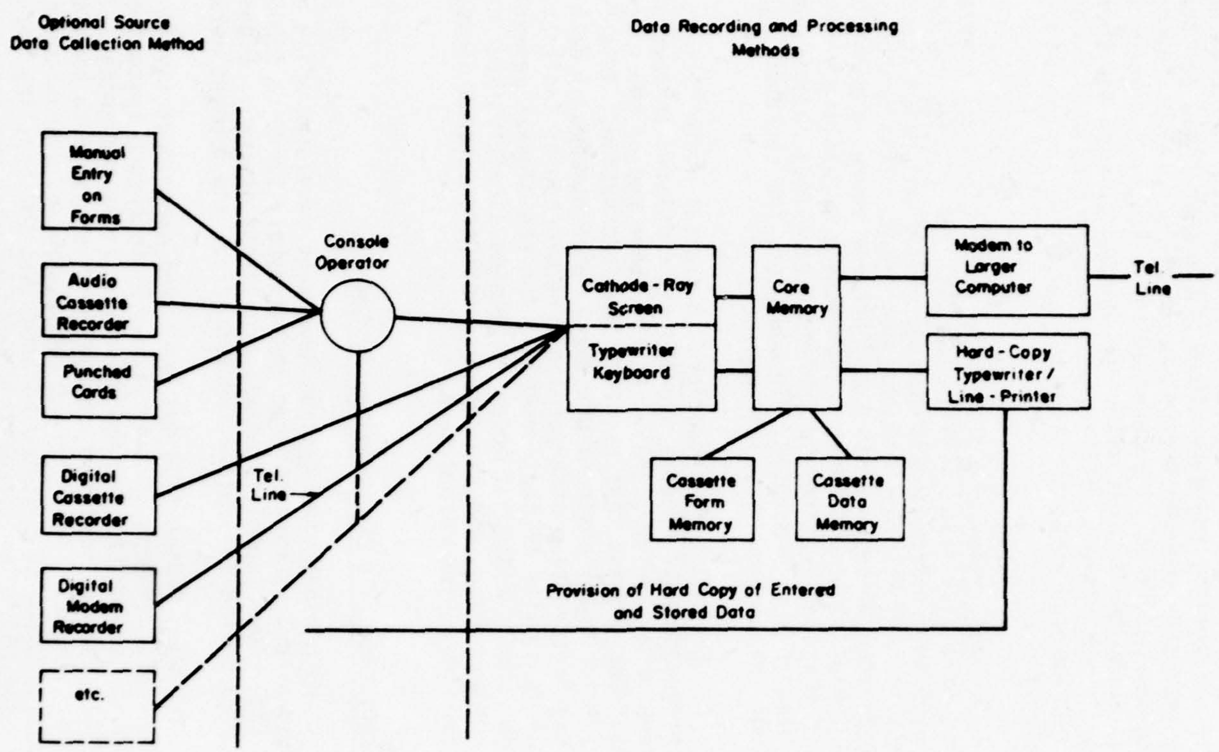

Figure 4. Optional methods of source data collection and information storage and processing.

equipped with additional keying, display and cursor indication, a core memory, and a power supply box; and either a typewriter or line printer for providing hard copy. The modem provides for communications between the remote location and the base.

An important feature of this system is that the programming language is BASIC.

The console can accommodate two digital memory cassettes. One of these provides interrogative and data formats. For example, the parameters that must be entered into the data base such as date, time, operating status, and maintenance performed are input to the computer terminal. These subsequently appear as questions to the personnel entering the data. The acquired data elements are overlaid on the second cassette. A standard form was transcribed to machine format for a System 2200 to record data; this system includes provisions for interrogative and data-error checking. A normal 8 x 10-1/2 in. form can be transcribed in approximately 4 hours. Appendix B provides an example of a transcribed form. The Wang system has two additional capabilities for collecting and recording historical and present data -- data reporting and trend analysis.

Data Reporting

The data-reporting section consists of a set of cassettes. These cassettes contain all records included on the first page of the manual system (Form 1); as the maintenance actions are completed, they are recorded on that set of cassettes. Hard copies of forms on which new entries have been made can be provided to maintain present procedures.

Trend Analyses

The major reasons for requiring hourly entries for readings of operators logs and similar reports are (1) to insure that the important monitoring points are visually inspected on an hourly basis, and (2) to provide information on trends of critical data. Usually, these logs are examined by supervisors at the beginning of a shift to determine if acceptable limits of the readings are being approached; this will determine whether corrective actions are necessary. If there is visual inspection of the meters, it would be possible to reduce the requirement for entering such data on an hourly basis. Then, on the basis of information entered every 2 hours, for example, trend analyses and actual data plots could be performed automatically and presented for examination. As an interim measure, the hourly recordings could be made manually; in addition, provisions could be made for entering any number of strings of data points into the system, and for performing trend analyses on such data, complete with display plots.

This computerized system for source data-collection, data recording, and storage of historical and present data is completely flexible. It is compatible with techniques for collecting source data both manually (on forms) and automatically (transcription). It allows data to be consolidated discreetly (i.e., item by item) into prescribed data formats for later analysis whenever it is available.

5 FUTURE DATA-COLLECTION METHODS

Current Problems

Manual methods of collecting, storing, retrieving, and analyzing data have the following deficiencies:

1. Analysis results frequently indicate that detailed data is required over longer time periods; this data may or may not be available, or may require more investigation to acquire.

2. Analysis is costly and time-consuming and requires highly trained and experienced personnel to interpret and place data into the necessary formats.

3. Facility operational or maintenance personnel cannot obtain rapid indications of potential long-term problems.

4. Timeliness of results is questionable.

Analyses of recorded data are necessary (a) to optimize design, (b) to compare available equipment for procurement purposes, and (c) to compare forecasts of a facility's RAM characteristics for mission availability with those of mission requirements. (Appendix A provides a number of sources for data analysis.)

Future Improvements

Automatic data recording and reporting will probably be required in future installations. Because of equipment costs, normal EMS installations will not be able to use redundancy techniques and paralleled equipment units at critical points in the system. Future installations will probably use automated control and monitoring techniques and presumably depend less on manual operations and maintenance methods. Thus, the possibilities of unattended operation will be exploited, and response times to failure conditions will be improved. It is anticipated that these improved means of acquiring source data will reduce the cost of data acquisition, reduction, analysis, storage, and retrieval procedures by 2 to 5 cents per data frame.

Advances in controls and instrumentation technology have made analog control devices less acceptable. New methods have been developed for accurately controlling and monitoring most parameters of power plants by digital methods. The increased requirements for energy conservation and environmental control of power-plant effluent has

necessitated the development of better control systems and the means to adapt existing digital technology to such controls.

Design criteria for the construction of military facilities (including power plants) which require digital controls will also provide for automated data-collection systems interfaced with the control system and with the automated energy-control systems.

6 RECOMMENDED COLLECTION METHODS

The recommended methodology for collecting historical data is defined by BAARINC and the Bechtel Corporation.[4] These organizations recommend that all records relating the equipment should be microfilmed; the events offsite are then reconstructed because the necessary data to support RAM and LCC studies are kept in various records within a facility.

The following are recommended data collection techniques:

1. Maintain hourly operating logs to assess performance and to note daily energy and miscellaneous supply usage.

2. Consult the Operating Engineer's or Plant Foreman's log to determine whether the downtime was caused by human or electrical/mechanical failure, standby, idle, preventive maintenance, or corrective maintenance action.

3. Consult the Maintenance Engineer's or Plant Foreman's log to determine the cause of electrical/mechanical failure, and to determine the "total-time-to-restoration" caused by preventive maintenance, diagnosis, obtaining parts, disassembling and reassembling equipment for electrical/mechanical part replacement, and checkout.

4. Use the accounting or procurement logs to determine the cost of repair parts, energy used, and miscellaneous supplies.

Methodology for collecting both present and future RAM and LCC data from operating electrical and mechanical systems and the equipment required to obtain and store it has been developed; this methodology and equipment can be used both in present systems and in future automated systems.

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[4] Booz, Allen Applied Research Inc., Data Systems Procedures, AD871151L (Department of the Army, May 1970).

Recording O&M Data

When recording O&M data, several characteristics require consideration:

1. Operational data, which is used to assess EMS performance and daily supply usage, is almost always recorded in numeric values; therefore, current data can be collected easily by digital recording equipment.

2. O&M data, which is used to record trouble or failure, is almost always noted in comment form on the operational log sheets and in log books; therefore, this type of data requires alphanumeric recording equipment. This equipment can be either portable or fixed, because the operating engineer or foreman is usually located in the central office.

3. Maintenance data, which denotes action taken to accomplish work specified by a maintenance work order, is usually noted in both commentary and numeric form. These types of data are not uniform, because the work is mainly equipment-dependent; thus, there are no standardized forms. This lack of standardization limits application of direct machine-entry recording techniques. Thorough investigation indicates that mark-sense type data recording is most suitable for this application, because both standardized and nonstandardized operations can be adapted for each type of equipment.

The present data acquisition system can be automated readily because equipment and technology for machine collection of the data are available. The methodology developed will cause minimum impact on existing recordkeeping systems and will supply the equipment user with a quantity of data never before achieved because of a lack of adequate manpower.

A system configuration recommended for collecting present and future data provides four major features: (1) a data-recording system, (2) data transmission offsite, (3) operational source-data reporting, and (4) a maintenance-record system.

Data-Recording System

A centrally located set of terminal equipment consisting of a data terminal with an online memory and a cathode ray tube display and keyboard is provided. The online memory is supplemented with flexible disks because: (1) the flexible disks will be capable of storing all the programs necessary to control operation of the terminal, and on a separate disk, all the data to be entered into the system; and (2) the

data entered will be stored in isolated blocks, each of which is pertinent to one reporting form. A high-speed line printer will provide hard copies of the data entered for reports required periodically. The estimated time required to produce the equivalent of a completely filled-out manual form is less than 2 minutes.

An optical reader (mark-sense type) is also provided. Although this equipment is used primarily to enter information associated with maintenance-data reporting, it can also be used to enter operational data. The optical reader can operate directly through the terminal to the flexible disk record storage.

Data Transmission Off-Site

A provision in the terminal equipment for a modem, under the control of the terminal supplies a means of transmitting desired data off-site. The data would be transmitted in the format developed; thus, completely executed data that would be equivalent to a completely filled-out manual report form could either be reproduced in hard copy, or stored in digital form in a remote location.

Operational Source-Data Reporting

Operations data which is presently recorded manually will be reported by operators using alphanumeric digital recorders. Several source-data recorders are available commercially; some are based on cassette-tape memories, and some on built-in, solid-state memories. Those having built-in memories are recommended for this application. The number of data records that can be stored is adjustable so that a single unit can record all of the hourly required readings, or a small number of recorders can be used for various classifications of readings. The stored information can be transferred automatically to the terminal by telephone or by direct connection; it can be transferred for remote locations by using a modem unit and a telephone connection.

It is also feasible to use mark-sense data logging for certain types of data. This system could be used to enter the time of failure, the time of start of repair, the time of repair completion, and the time available for use; both operations and maintenance employees could use a common reader and a common input sheet. The mark-sense sheets could be used with an optical reader to transmit information directly to the terminal.

Maintenance-Record System

The manual recording system would be replaced, which would provide a number of advantages to the facility and to O&M personnel, and would provide more accurate data.

The provisions for output data of this system are:

1. Automatic display of out-of-limit input readings
2. Hard-copy information in equivalent formats
3. Hard copy of daily inspection and overhaul schedules
4. Hard copy of monthly summary information on operations
5. Parameter trend reports on critical equipment.

Since between 60 and 80 percent of the data required to complete failure-event analyses (the data represents the information necessary for RAM evaluations) are derivable from maintenance-reporting, the automated system permits direct use of recorded maintenance-system data, which is already formatted in the CRAM format.

The collected data can be retrieved automatically, and the required analysis procedures can be documented and programmed by computer operators. Most of the analysis time can therefore be devoted to examining the outputs of the computer runs, with only a minimum amount of time expended for data handling and ordering.

7 ADVANTAGES OF AUTOMATED SYSTEM

Advantages to Facility Personnel

Operational Personnel

Operators will be able to carry hand-held digital recorders or mark-sense holders, rather than current data-sheet formats which must be entered manually. The entered data are visible and can be checked against the meter indications before they are placed in temporary hand-held storage. When entering the hand-held stored data into the terminal, error checking and out-of-limit indications permit rapid validity checks. Corrections, if any, can be implemented quickly.

The operational workload for data gathering will be reduced by at least 50 percent because of improved data-handling and reporting techniques.

Hard copy of reported data will be available on demand after the hand-held stored data are entered into the terminal.

Indications of out-of-limit conditions for reported data on critical parameters will be available as soon as the hand-held data are input into the terminal. The opportunity to review and modify incorrect data will be available at this time. Correctly entered out-of-limit conditions will be flagged and presented on hard-copy reports.

Operational reports will be clear and legible, and if the report is inadvertently damaged, it can be reproduced within minutes.

Chronological histories will be developed automatically from daily operational reports.

Daily updating of inspection and overhaul schedules of the generator sets will be provided automatically, on command.

Monthly summary reporting information required by the facility superintendent about monthly operations will be provided automatically, on command.

There will be better coordination among activities of O&M personnel because of improved communications.

Maintenance Personnel

Out-of-limit conditions will be indicated and identified immediately after the reported data are entered into the terminal. Hard-copy reports of operational data will flag indicated out-of-limits conditions.

Some preventive maintenance tasks will be rescheduled automatically during the month; the remainder will be compared against forecasted available manpower, and lower priority tasks will be shifted to the following month.

Preventive maintenance tasks for the following month will be rescheduled automatically by comparing labor requirements of the executed tasks against forecasted available manpower.

No additional workload will be imposed on maintenance personnel for identifying and reporting corrective maintenance tasks.

Log forms and data-reporting procedures for generator sets will have the same data-flow status as all other maintenance operations.

The reporting load of the maintenance foreman in charge of generator sets will be reduced.

The monthly summary reporting information required by the facility's Superintendent for Maintenance Activities will be provided automatically.

Trends of critical parameters will be provided on command.

There will be better coordination among the activities of O&M personnel because of improved communication.

Cost Reporting Personnel

Costs of spare parts and supplies will be provided by individual task, thus furnishing better information for LCC analysis and spare-part procurement planning.

Historical trends will be available after 1 year or less of operation for forecasting stocking requirements and reducing inventories.

Supervisory Personnel

Reports will be forwarded to higher headquarters in a neater and more legible form. The reports will be prepared automatically on demand.

Report formats produced automatically can be legibly reduced to microfilm, which will alleviate bulk record storage at the facility. If necessary, originals can be retained at a central archive.

Information required for a monthly summary report will be provided automatically on demand. This will impose no additional load on either operations or maintenance personnel.

The maintenance supervisor's reporting workload will be reduced, thus allowing more time for re-examining personnel operations and developing better preventive maintenance techniques.

Usage history of spare parts and supplies used for maintenance activities will be available by month, which will help justify ordering parts and supplies.

The flexibility of the automated system will facilitate modifications to procedures and methods.

Advantages of the Automated System to Personnel Requiring the Analyses

The following paragraphs outline the advantages derived by data recipients from the automated system:

The proposed automated system will be adaptable to future facilities that use automated data reporting and operational monitoring equipment. Interfaces between sensors and the data-reporting system will consist primarily of timing controls. Out-of-limit recognition in a data-reporting terminal will allow rapid early warning of possible trouble or failure in critical subsystems. Automatic data logging and storage facilities will permit trend analyses.

The ability to transmit data stored on disks to a central facility will eliminate present field trip and microfilming requirements. Data transmission will be by telephone lines to a central location. In remote locations, or in situations where data may be classified, the flexible disks will be replaced and shipped to a central facility for processing.

The new system will simplify the analyst's problem of reconstructing chronological histories for paralleled equipment subsystems, because it will record all switching information automatically.

Data elements relative to failure events will be prearranged in the correct analysis format.

Responses to requests for analyses of installed subsystems for either RAM or LCC evaluations can be answered on a more timely basis.

Investigations and developments of shorter "sampling" techniques for RAM analyses can be examined, based on the availability of more timely and complete data.

8 EQUIPMENT FOR AUTOMATED SYSTEM

Equipment Manufacturers Survey

In support of the methodology developed for data collection, a vendor search was made to identify manufacturers of the following types of equipment:

1. Portable hand-held or cart-mounted digital and alphanumeric-data-entry equipment which can store entered information and later transmit the stored information to the host minicomputer which will be located at the O&M center.

2. Fixed minicomputer systems having direct entry keyboard, dual disk drive unit (one for program and one for storage), CRT display, and line printer; having interfaces to receive data from portable digital devices and from optical scanning equipment; and having an interface to transmit stored data to an offsite computer center.

3. Optical scanning equipment which can recognize numeric characters and normal mark-sense marking. (Note: alpha character recognition, voice recognition, and magnetic-ink character recognition equipment were not seriously considered because the cost was prohibitive and the state of the art was uncertain.)

The survey of the data-processing equipment manufacturers included, but was not limited to, approximately 50 manufacturers. The survey indicated the following information.

1. A review of vendors of portable hand-held or cart-mounted digital recorders indicated that portable hand-held devices are readily available for recording operational data and cost approximately $2000 on a single-quantity basis. Cart-mounted portable recorders were not included because the price started at $4000.

2. A review of vendors of fixed minicomputer systems, including peripheral equipment, indicated that most of the major computer companies are beginning to market these items (e.g., WANG System 2200, IBM Model 5100, Hewlett Packard 9830, Data General, etc.) and that they are readily obtainable. The minicomputer with peripherals ranges between $20,000 to $40,000, based on a single-unit purchase.

3. A review of vendors of optical scanning equipment indicated that only one manufacturer markets a unit suitable for data-collection application. This is the Optical Scanning Corporation's Model 17; the equipment costs $11,500, based on a single-quantity purchase.

Estimated Automated-System Equipment Costs

The estimated equipment costs for the automated system are based on informal quotations on equivalent system components from two potential minicomputer suppliers. In some cases, some equipment items originate from the same source for both suppliers; however, other potential suppliers have not been examined yet. The costs shown in Tables 1 and 2 for the WANG System and the DATA GENERAL System, respectively, are based on a General Services Administration discount of approximately 15 percent, which is standard for these types of components.

Both systems use "Flexible-Disk," random-access memory to store the program and data. There have been no extensive technical evaluations which would warrant recommending one of these two terminals; however, both systems have been proven capable for commercial application. IBM, Hewlett Packard, and others have introduced similar systems. These are not included in the analysis, because the available information is limited.

Duplicate Equipment

The proposed automated-facility system includes the costs of procuring duplicate sets of system equipment. This will make it possible to check problems of interaction between a field installation and a central facility, including the transfer of data streams. In addition, it will be possible to verify that error-free data have been received at the central facility, and that methods and procedures have been used at the field installation for updating files and keeping adequate data storage available for current data. The plan insures that all system equipment which will be used at the field installation will have been checked for operational status before application.

Table 1

Estimated System Costs (December 1975),
WANG Laboratories, Inc.

1.	*Terminal Equipment*		
	Model 2200-S Processor	$2,400.00	
	Option 24 1/0 Controller	1,600.00	
	16k Core Memory	3,400.00	
	Model 2226 CRT	2,600.00	
	Interfaces with OPSCAN	300.00	
	Subtotal		$10,300.00
2.	Flexible Disc Memory (3 Discs, 786,432 bytes)		6,000.00
3.	High-Speed Line Printer (80 columns)		3,300.00
4.	Telephone MODEM and Interfaces		1,000.00
5.	Optical Scanning Corp OPSCAN Model 17		11,500.00
6.	Hand-held Source Data Digital Recorders (2)		5,000.00
	Total Estimated Costs		$37,100.00

Table 2

Estimated System Costs (December 1975), DATA GENERAL

1.	Terminal Equipment		
	Model 8491 NOVA 3/12 Computer	$4,590.00	
	16k MOS Memory	425.00	
	Model 8432 Battery Back-up	340.00	
	Model 8530 Auto Progr. Load	170.00	
	Model 4077 Assy Line Contr.	128.00	
	Model 4078 EIA	43.00	
	Model 6012 CRT	2,300.00	
	Interfaces with OPSCAN	300.00	
	Mounting Rack	950.00	
	Subtotal		$9,246.00
2.	Flexible Disc Memory Two Model 6030 Flexible Disc Sets (786,423 bytes)		6,120.00
3.	High-Speed Line Printer - Model 31		3,300.00
4.	Telephone MODEM and Interfaces		1,000.00
5.	Optical Scanning Corp OPSCAN Model 17		11,500.00
6.	Hand-Held Source Data Digital Recorders (2)		5,000.00
	Total Estimated Costs		$36,166.00

9 MANPOWER REQUIREMENTS FOR ONSITE OPERATION OF AUTOMATED SYSTEM

The automated system design has been based on maintaining congruency with an operational facility's present data-handling procedures. The defects inherent in the system configuration used in a field experiment, which did not guard against entry errors, have been eliminated in the revised system. Digital cassette tapes* were used to store both the programs and the data, and had to be changed frequently. For instance, the data recorded for the generator sets was maintained separately by using a different cassette for each generator set; this resulted in several human errors. In addition, the inability to use digital cassettes in a random-access mode of operation necessitated considerable processing time to produce hard-copy reports. Report processing time was 15 minutes with digital cassette data storage techniques.

The difficulties of human error and long processing time have been overcome by using flexible disks to record data and data-processing programs. These disks are designed for random access, so that the production of reports in hard-copy form is reduced to less than 2 minutes. The storage capacity of a single flexible disk is 262,144 bytes; thus, one disk can store all the programs required to operate the system, as compared to four cassette tapes. The additional flexible disks would store all the input data, providing 524,288 bytes of storage. This storage capability would be sufficient to record both operational and maintenance data for at least 2 months at a typical facility. After the data is transferred automatically to a central facility, the disks will be reusable. The facility must retain information entered for the past month to produce monthly summary reports. Originally, the manual procedure kept all of the past month's data, but the new procedure will store the summarized trend and reference data necessary to prepare facility reports.

Field experiment indicates that O&M personnel can use the automated system with minimal training; thus, special computer operators are not required. Furthermore, using hand-held source-data digital recorders and/or mark-sense sheets will reduce the data-reporting workload on O&M personnel by nearly 50 percent, and increase the time available for more productive work.

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* Digital cassettes were initially used because they were cheaper; however, later studies indicated that they were not cost-effective.

The manpower required to transfer the recorded data in a useful form to a central facility (a central clearinghouse) is negligible. A telephone connection is first made between the terminals at the facility and a central location; next, the reading and transcription of the data stored on the flexible disks is designated for storage; finally, transcription onto comparable disks at the central facility is accomplished in less than 5 minutes at normal data-transmission rates.

10 RECOMMENDED DATA-BANK ORGANIZATION AND CLEARINGHOUSE OPERATION

Data Bank

Figures 5, 6, 7, and 8 illustrate data collection, storage, and usage.

Historical data should be entered on CRAM forms (not statistically analyzed) which are similar to Office of the Chief of Engineers (OCE) Forms I and II. This form is currently being refined for RAM and LCC data-bank application. When this is completed, the source data can be organized and the filled-out form used as a RAM/LCC data bank. Since forms are structured for computer processing, they can be kept as they were originally and stored manually, or be keypunched and stored by the computer. This data can also be microfilmed at the site; processing can be done offsite, and checking and screening for duplication and error can be done by a central clearinghouse.

The data collected will be computer-processed, using OCE data procedures to create a data bank of input information (not statistically evaluated) on magnetic tape for RAM and LCC. The data collected can be filed manually, creating a manual data bank which will be copied periodically for use in manual statistical evaluation. The data output from this system would be the events affecting mean time before failure (MTBF) and mean time to repair (MTTR), i.e., chronology, failure, maintenance, repair, and time for parts delivery. Load-profile information would be included, if available.

Present and future data will be collected with machine aids to form a statistically evaluated data bank. Computer aids will be used to retrieve nonstatistical EMS-RAM data. This data will be computer-processed, using the OCE data procedures computer program. This will create an EMS-RAM data bank on magnetic tape of statistically analyzed RAM type data, with an expected confidence of approximately 95 percent.

Manual methods, aided by a programmable calculator, can also be used to store data. EMS-RAM data can be retrieved manually from a computer-created data bank or from a manually created data file; together with the calculator, this data can be used to make statistical estimates of MTBF and MTTR, based on the Weibull failure rate distribution function. This will manually create an EMS RAM data bank (statistically supported), with an expected confidence of approximately 50 percent.

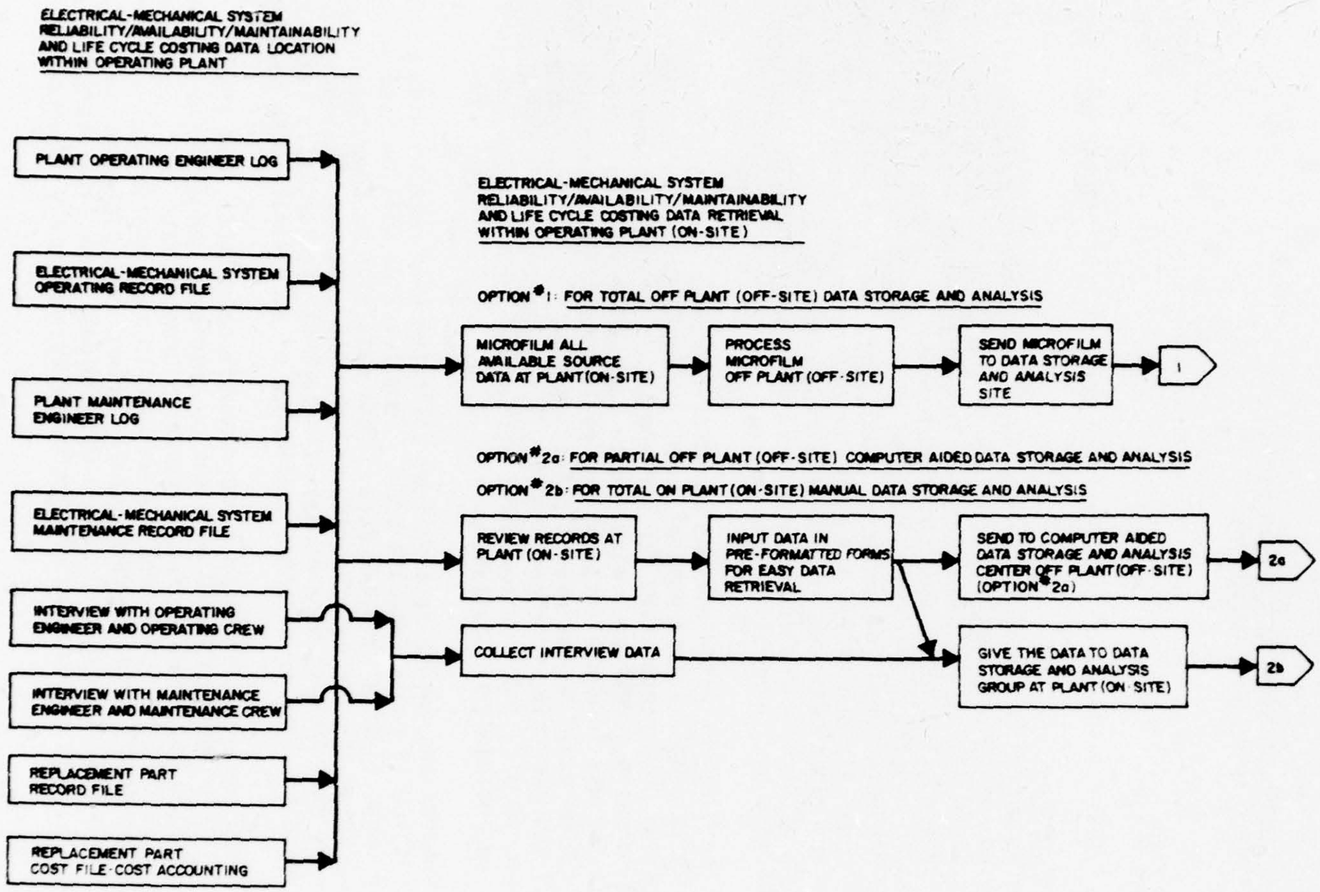

Figure 5. Data collection methodology.

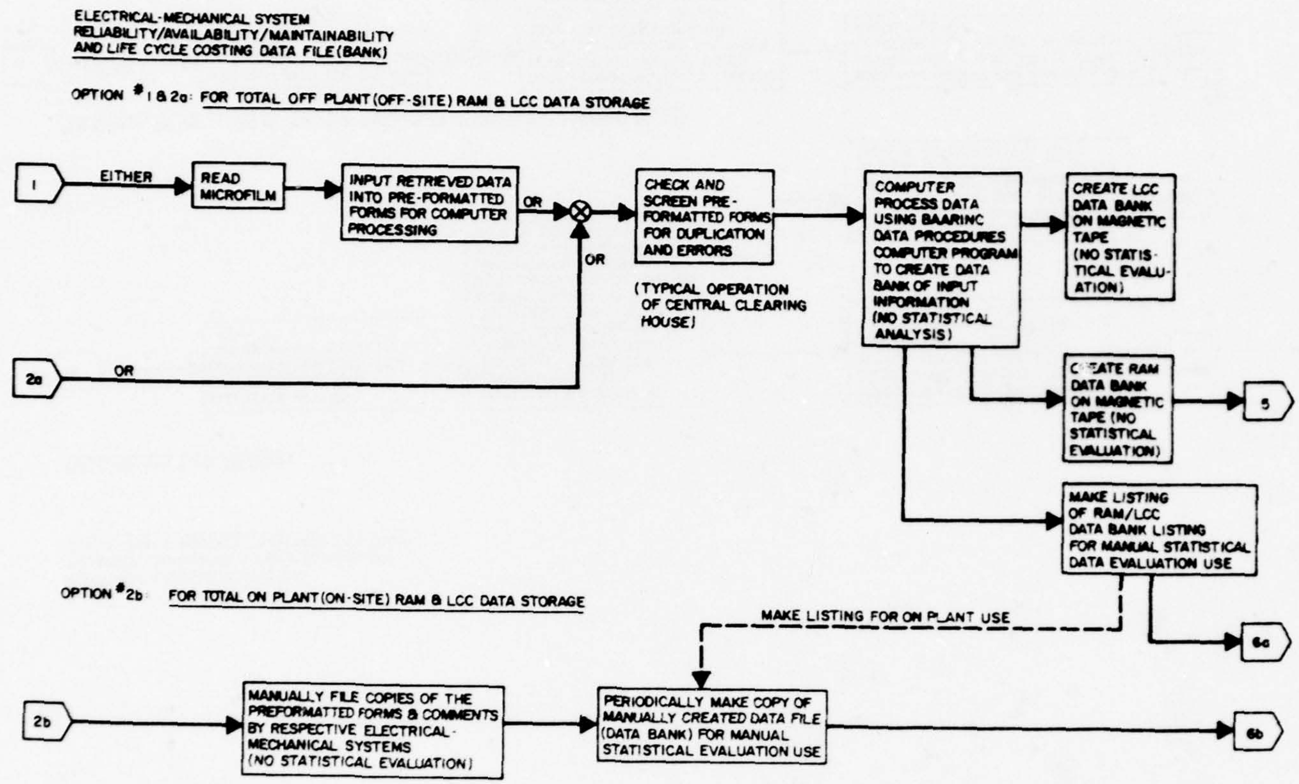

Figure 6. Data storage methodology (no statistical evaluation).

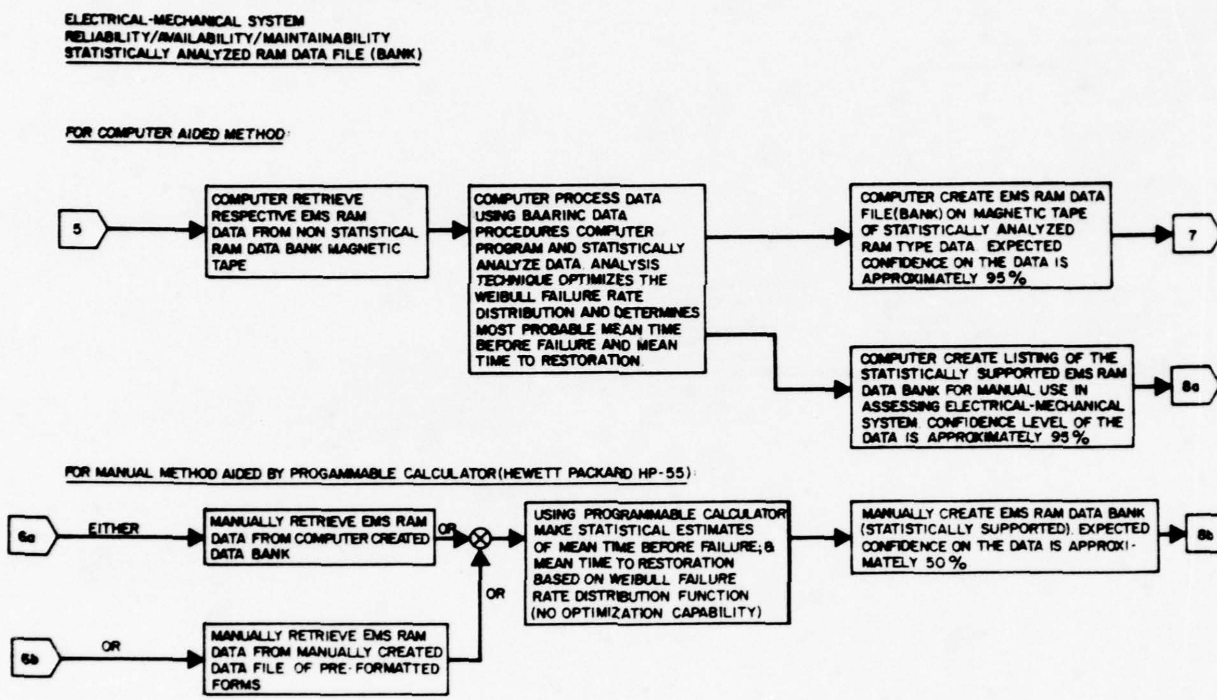

Figure 7. Data storage methodology (statistically evaluated).

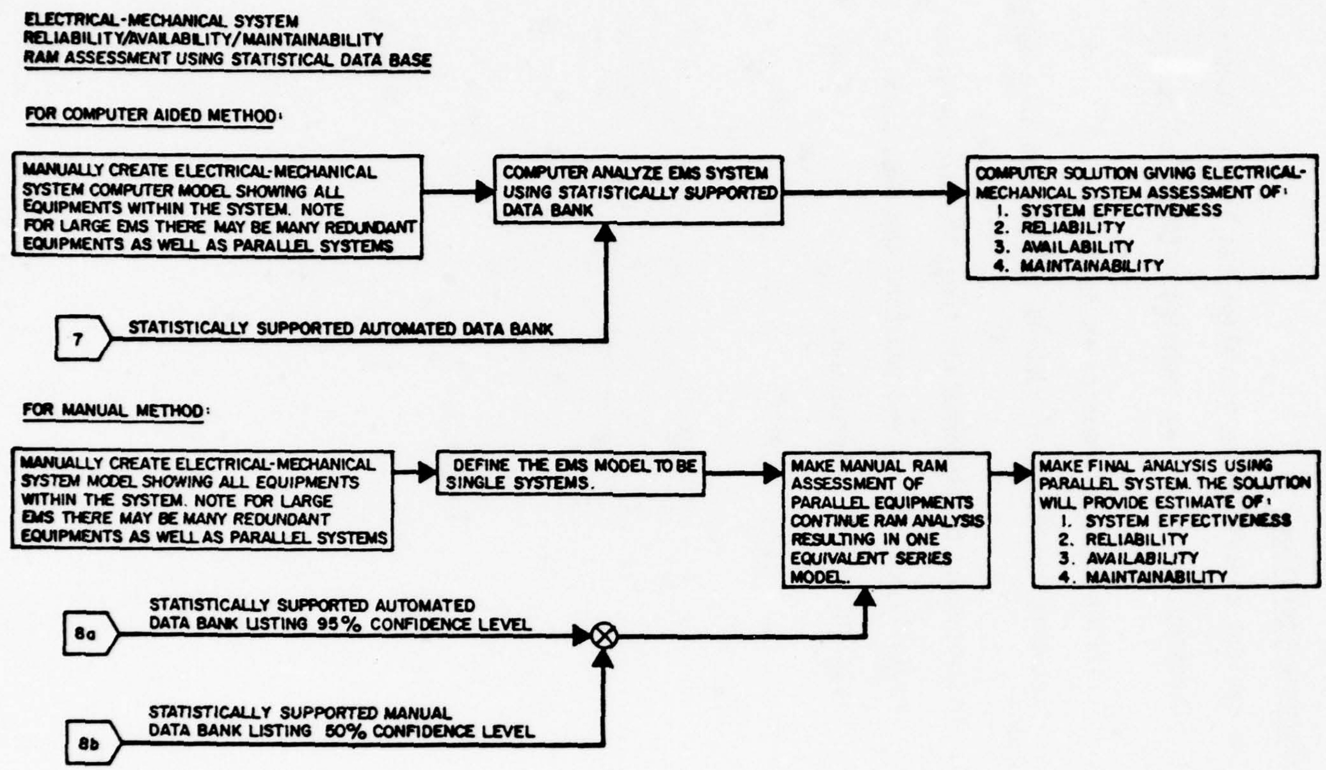

Figure 8. Data usage for RAM assessment.

Clearinghouse Operation

The central clearinghouse operation has several functions:

1. Checking and screening incoming information for duplication and error.

2. Verifying that information is correct.

3. Executing the means of putting information in a nonstatistical data bank.

4. Distributing the information from the nonstatistical data bank

5. Physically analyzing and updating the data bank

6. Distributing RAM information.

11 CONCLUSIONS

This research has produced the following conclusions:

Revisions to OCE Forms I and II will improve RAM and LCC analysis by providing the capability to enter discrete segments of data and to categorize such segments automatically.

An automated system will improve the means of acquiring source data and will reduce the costs of data acquisition, reduction, analysis, storage, and retrieval procedures by 2 to 5 cents per data frame.

An automated system will benefit O&M, cost reporting, and supervisory personnel, as well as personnel requiring RAM analyses.

An automated system requires only minimal training for O&M personnel, but can reduce their data-reporting workload by nearly 50 percent.

APPENDIX A:

ANALYTICAL TECHNIQUES AND
DATA SOURCE

Analytical Techniques for Assessing EMS and Electrical and Mechanical Equipment (EME) RAM

Since EMS and EME are repairable and maintainable throughout the life of the equipment, a literature search was conducted to determine current techniques in assessing their RAM factors. Applicable literature references and annotated comments have been included.

Literature review has shown that limited work was done in developing new analytical techniques to assess the RAM of such EMS and EME. Further research and development will be required to develop generalized procedures for assessing the RAM of general EMS and EME which continuously need maintenance and repairs.

1. Amstadler, B. L., Prediction of System Reliability by Method of Bounds, Reliability and Maintainability Symposium, Boston, MA (1968), pp 423-448. The system reliability was determined by initially calculating the upper and lower reliability limits and then combining the results to arrive at the final overall system reliability. In this analysis, maintained systems have been ignored; however, the methodology presented is unique, because reliability estimates were treated as mathematical limit problems.

2. Billington, Ray, "Bibliography on the Application of Probability Methods in Power System Reliability Evaluation," IEEE Transaction on Power Apparatus and Systems, Vol DAS-91, No. 2 (March/April 1972), pp 649-660. This article presented a computer-aided procedure for determining reliability of serial and redundant components. The procedure is not capable of handling repairable equipment.

3. Burjacott, John A., "Network Approaches to Finding the Reliability of Repairable Systems," IEEE Transaction on Reliability, Vol R-19, No. 4 (November 1970), pp 140-146. This paper presented a bibliography for the power-system reliability evaluation, but none of the entries considered all the factors related to estimating the reliability of maintained systems.

4. Cici, A. S., and V. O. Muglia, "Computer Reliability Optimization System," IEEE Transactions on Reliability, Vol R-20, No. 3 (August 1973), pp 110-116. Two approaches were described: (1) successive reduction of the network, and (2) nominal paths or cuts. Of the

two methods presented, only the series/parallel system approach appears to be practical. Manpower allocation was not considered.

5. Feely, John M., A Method of Predicting and Apportioning System Effectiveness Estimators, 10th Annual West Cost Reliability Symposium, Beverly Hills, CA (February 1969), pp 135-155. This paper presented the system organization of computer programs written to handle reliability calculations covering design, production, and field application phases applicable to electronic systems. The computer programs do not consider maintained components.

6. Fleming, Janus L., "Relcomp: A Computer Program for Calculating System Reliability and MTBF," IEEE Transactions on Reliability, Vol R-20, No. 3 (August 1971), pp 102-107. This paper presented a method for determining the availability and reliability of pseudo-maintained systems. This method does not allow for multiple failures nor does it consider manpower availability directly.

7. Kim, Y. H., K. E. Case, and P. M. Ghare, "A Method for Computing Complex System Reliability," IEEE Transactions on Reliability, Vol R-21, No. 4 (November 1972), pp 215-219. This paper presented a method for converting a series/parallel system of components into a probalistic graphical format. The graphical result was used to compute reliability. Only nonrepairable components can be considered in this method of analysis.

8. Krishnamurthy, E. V., and G. Komissar, "Computer-Aided Reliability Analysis of Complicated Networks," IEEE Transactions on Reliability, Vol R-21, No. 2 (May 1972), pp 86-89. The algorithm presented a process whereby a complicated network of components was reduced into smaller sets of manageable parts before reliability calculations were made. This methodology only considered nonrepairable components.

9. Spann, A. C., "A Synergistic Reliability and Maintainability Prediction Package," Proceedings of the 1973 Annual Reliability and Maintainability Symposium (January 23-25, 1973), pp 542-549. This paper presented an online system for computing the reliability of a maintained system which considered maintenance policy and spare parts inventory; however, the procedure requires all models to be in serial (or reducible to serial) form. Furthermore, the procedure does not provide for manpower allocation. Although the program appears to be the closest simulation system available for handling repairable systems of arbitrary configurations, the procedure appears to be too restrictive for general application.

10. Tiger, Bernard, System Effectiveness by Computer, Reliability and Maintainability Symposium, San Francisco, CA (1972), pp 59-67. This paper presented a simple computer-aided method for calculating MTBF availability and survival of complex systems; however, the repair time must be relatively small as compared to the MTBF of the system for the approximation to be valid. The procedure is limited to series models only.

11. Van Slyke, R., and H. Frank, "Network Reliability Analysis, Part 1," Networks, Vol 1, No. 3 (1972), pp 279-290. Although the title appeared to be applicable to the situation, this procedure used a communication type of network modeling which was described by nodes and links and which were subject to failure. This methodology did not really address the problem of repairable component reliability.

12. Vokac, T., R. L. Burke, and C. L. Muriby, Steady State Availability of Power Systems, Electronic Computer Program Abstract, Program Number 712-C8-R501B (U.S. Army Construction Engineering Research Laboratory [CERL], December 1973). The computer-aided procedure was originally developed to determine the availability of maintained electric-power generation and distribution systems having "N" numbers of identical power generation modules, up to four motor generator sets, and up to three commercial power interties in parallel operations. The power generation module is treated as having "M" number of series equipment and further allows consideration of equipment operation, corrective maintenance, and preventive maintenance activities. Even though the procedure was created solely for the power generation and distribution system availability assessment, the procedural approach can be readily applied to a wide range of maintained electrical/mechanical systems and equipment. This computer-aided procedure as currently written cannot be easily adapted to any electrical/mechanical system.

Identification of Mission Critical EMS Installation Within a Fixed Military Installation

A detailed review by BAARINC of Army Regulation 415-28 identified 12 different types of EMS which were necessary to support Army-constructed facilities operation.[5] Then, each EMS was placed into a simulated failure state to determine whether any of the identified EMS failures caused "risky" or "hazardous" operation for the facility classes when completing their intended missions; "risky" operation was defined as a

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[5] Department of the Army Facility Classes and Construction Categories, AR 415-28 (Department of the Army, 10 August 1973); Booz, Allen Applied Research Inc., Data Systems Procedures, AD871151L (Department of the Army, May 1970).

chance that a future facility-class mission would be aborted because of EMS failure. "Hazardous" operation was defined as a chance that a future facility-class mission would be aborted because of physical EMS failure causing damage to either the facility and/or to the operating personnel. Table 1 of the review by BARRINC presents the resulting failure-state analysis.

In order to identify the critical EMS installation, all the "risk" and "hazard" events were summarized as a function of EMS and facility group class. The letters "H" or "R" were assigned to the "hazard" and "risk" situations, respectively, and if both situations existed, the letters "R,H" were assigned. Then, the "R" and "H" were totaled for each EMS, and the respective percentages were calculated. Table 2 of the BAARINC review presents the resulting matrix. However, the summary did not clearly indicate the hierarchy of critical EMS; therefore, the results of Table 2 were further categorized, based on "R," "H," and "R&H" events, and the EMS ranked based on highest number of occurrences in "R" "H" and "R&H." Table 3 of the review presents the resultant ranking. The results shown in Table 3 indicate that some of the EMS were commonly ranked high (within the first five) when "R" "H" and "R&H" events were considered separately. Based on the number of "R" "H" and "R&H" occurrences within the first five rankings, the events were reranked as a function of EMS. The results of the ranking are presented as Table 4 of the BAARINC review.

The data in Table 4 show firefighting, water, and sewage systems to be the highest ranking. However, the current design practices consider the EMS of these three in great detail, and they are built in accordance with national codes; therefore, these EMS were, in effect, eliminated from further consideration. The remaining EMS included electrical, lighting, heating-ventilation-air condition (HVAC), chemical handling, fuel, and pneumatic systems as possible critical EMS. One of the common needs of the remaining EMS was electrical power both to drive the prime mover involved with HVAC, chemical handling, and the pneumatic system, and to provide lighting. Therefore, the most critical EMS would be electric-power distribution and/or electric-power generation systems. This should be followed by the HVAC system.

Identification of Available Data Types From Historical Records

Using the previously identified critical EMS (electrical power generation and distribution system) as a reference, the data collection efforts were accomplished during September and October 1973 as a joint effort between Kwajalein Missile Range (KMR), OCE's Advanced Technology Branch, and the U.S. Army Construction Engineering Research Laboratory (CERL), using the BAARINC source-data acquisition procedure. This site

was selected because the power plant was continuously operated to provide electric power and because data on the same power plants had been collected from 1962 to 1966. The 1966 to 1973 data was collected from the following KMR power plants:

Power Plant No. 1 (ZAR)	Nine - 1500 kW, 327 rpm Cooper - Bessemer/EMC
Power Plant No. 2 (BATTERY)	Six - 800 kW, 450 rpm White/Westinghouse
Roi Namur Power Plant	Nine - 1500 kW, 900 rpm Alco/Westinghouse
Meck Island	Nine - 1500 kW, 900 rpm General Motors/Electric Product
Illeginni Power Plant	Four - 800 kW, 1200 rpm Caterpillar/KATO

The collected data was analyzed at CERL, using the OCE procedure. Even though the collected data was extensive, and the data reduction efforts were limited to the Roi Namur Power Plants, some needed data was missing: the maintenance foreman/engineer logs and the maintenance technical reports. As a result, only gross availability assessment and overall LCC assessment were possible.

Identification of Available Data Type From Current Records

To identify current data availability, a diesel-electric power plant was selected for study, since historical data was also collected on such power plants. A search to determine which military installation was generating electricity continuously revealed that the USAF SAGE Power Plant, 25AD, McChord AFB, Tacoma, WA, had a continuously operated diesel-electric power plant.

Using past data-collecting experience, researchers reviewed the plant to insure that all the data necessary for assessing RAM and LCC would be available. The study indicated that all the necessary data was available; however, data older than 2 years was not available on the base in conformance with a Government regulation; i.e., after 2 years, all the data is sent to the central archives to the USAF Air Defense Command.

Identification of Current Sources of RAM and LCC Data

A study identified the following current data sources which could be used to obtain RAM and LCC data for EMS:

1. An AFM-66-1 data bank maintained by the U.S. Air Force for parts replacement logistics on the Minuteman Missile Systems.

2. A 3M data bank maintained by the U.S. Navy for general parts replacement logistics.

3. A RAM data bank developed by the U.S. Army to support SAFEGUARD system development.

4. A Government Industry Data Exchange Program (GIDEP) data bank maintained by Tri Service for assessing RAM, which is currently being administered by the U.S. Navy Missile Fleet Analysis, Corona, CA.

Since the purpose of the study was to determine data sources for assessing RAM, the Air Force's AFM-66-1 and the Navy's data banks were reviewed and found to be unsuitable because the replacement data within these data banks did not justify why the parts were replaced.

The data bank prepared for SAFEGUARD systems development is a suitable source, but the data bank is insufficient to support all EMS RAM assessment studies. Currently, the data bank primarily has data on the power plant, but does not cover all types and sizes of diesel-electric generator sets.

The GIDEP data bank is maintained by the Tri Services (Army, Navy, and Air Force) and the National Aeronautics and Space Administration (NASA). It was originally a cooperative venture between the user industries and the Government (Tri Service) for exchanging information on electronic component performance. The user industries -- i.e., industries that use components such as transistors, capacitors, resistors, etc., and that manufacture electronic equipment for the Government agencies' consumption -- would report failures or suspected problem areas with certain component manufacturers. This information was passed on to all participating Governmental agencies and industries. The shared data was used to obtain greater reliability from the final product and as a cost-avoidance factor for the project.

As a result of the rapidly increasing operating and maintenance costs and the need for more reliable products, the Energy Resources and Development Agency, the Mine Enforcement and Safety Administration, and the U.S. Postal Service have become participating members of GIDEP in hopes of reducing their operation costs through cost-avoidance programs. The data currently being entered into GIDEP has been expanded to include electrical and mechanical equipment.

APPENDIX B:
FORM SAMPLES

DAILY POWER PLANT OPERATING LOG (DIESEL ELECTRIC)

UNIT POSITION NO. 5 OF 6 UNITS	ENGINE MFG. ENTERPRISE	COMMAND ADC	BASE McCHORD A
PRIME POWER ✓ / STAND BY		MODEL DSQ-38	GENERATOR MFG. ELLIOT
	NAME PLATE RATING HP 1755 KW 1250	SERIAL NO. 57047	NAME PLATE RATING KW 1250

ENGINE TEMPERATURES

TIME	1. JACKET WATER IN	1. JACKET WATER OUT	2. LUBE OIL IN	2. LUBE OIL OUT	2. LUBE OIL TURBO OUT	3. AIR AIR TO FILTER	3. AIR BEFORE INTER COOLER	3. AIR ENGINE MANIFOLD	4. EXHAUST FROM CYLINDERS 1	2	3	4	5	6	7	8	9	10	11	12	TO TURBOCHARGER BR. I	BR. II	BR. III	FROM ENG. OR TURBO	5. ENGIN... COOLING WATER IN	OUT	LU... OIL
MON																											
0100	1	2	3	4	5	N/A	6	N/A	7	8	9	10	11	12	13	14			N/A			N/A		15	16	N/A	1...
0200																											
0300												P# 1 (D-)															
0400																											
0500																PARAMETER LIMITS MAX/MIN											
0600	155	165	165	175	175		1.0		750	750	750	750	750	750	750	750								750	16		6.
0700																								450	5		2.
0800												DEVIATIONS															
0900																											
1000												MAX 100°F READINGS															
1100												7 - 14															
1200																											
1300																											
1400																											
1500																											
1600																											
1700																											
1800																											
1900																											
2000												DEVIATIONS															
2100																											
2200												MAX 2 W. H_2O															
2300												33 - 40															

SHIFT	8. ENGINE PRESSURES - PSI FUEL OIL FILTER IN	FUEL OIL FILTER OUT	LUBE OIL FILTER IN	LUBE OIL FILTER OUT	CRANK CASE INCH H_2O	START AIR	AIR INCH H_2O AFTER INTAKE FILTER	AIR PSI BEFORE INTER COOLER	9. CYLINDERS FUEL PUMP RACK POSITION 1	2	3	4	5	6	7	8	9	10	11	12	10. LEVELS GOV. OIL	CRANK CASE SUMP	FUEL OIL DAY TANK	11. LUBE OIL MAKEUP GALS. DRIP-OFF	MAG ZEL	METER READING
0100	26	27	28	29	30	31	32	N/A	33	34	35	36	37	38	39	40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	41	42	
0900	35/10	35/10	65/25	65/25	0.5	250	0.5		26	26	26	26	26	26	26	26								3.0	3.0	METE... YE...
1700		P$ 2									PS	3	31	- 40												

14. ENGINE OPERATING HOURS	
PREV. TOTAL	
TOTAL TODAY	
TOTAL TO DATE	

15. ENGINE EXHAUST

☐ CLEAR
☐ VISIBLE
☐ DARK
_______ TIME

16. CYLINDER COMPRESSION AND FIRING PRESSURES
(Check after every 700 hours operation)

	1	2	3	4	5	6	7	8	9	10	11	12
COMPRESSION												
FIRING												
KW - LOAD												

TOTAL	
PREVIOUS	
TOTAL TO DATE	

REMARKS

17. DOWN TIME - HOURS	STANDBY	MAINT.	DEAD LINE
PREV. TOTAL			
ADDED TODAY			
NET TOTAL			

18. OPERATING PERSONNEL SHIFT	FOREMAN
1	
2	
3	
SUPERVISOR	

METER READING

METE... YE...

N...

1. CODE F...

N. NORM...

COMMAND	BASE	SITE	DATE
ADC	McCHORD AFB	SAGE POWER PLANT	

MODEL	GENERATOR MFG	MODEL	REVIEWING ENGINEER
DSQ-38	ELLIOTT	N/A	

SERIAL NO	NAME PLATE RATING KW	SERIAL NO	DATE REVIEWED
57047	1250	5510537	

4. EXHAUST									5. ENGINE PRESSURE - PSI						6. DEG OF TURBO VIBRATION	7. ELECTRIC GENERATOR							TIME
					TO TURBOCHARGER			FROM ENG OR TURBO	COOLING WATER		LUBE OIL ENG	FUEL OIL ENG	TURBO OIL	AIR ENG MANIFOLD		ALT TEMP	AMPERES			KW	PF OR KVAR	EXCITOR AMPS DC	
8	9	10	11	12	BR I	BR II	BR III		IN	OUT	IN	IN	IN				PH 1	PH 2	PH 3				
																							MON
14	—	—	N/A →		←	N/A	→	15	16	N/A	17	18	19	20	21	22	23	43	44	24	25	45	0100
																							0200
—	—	—	—	—	—	—	—	—	—	—	—	—	P$	2 (16	-31)	—				—	—		0300
																							0400
PARAMETER LIMITS MAX/MIN																							0500
750								750	16		65	35	35	6.0	–	80°C	155	155	155	1255	0.95	160	0600
								450	5		25					—	80	80	80		0.80		0700
→																							0800
																							0900
																							1000
																							1100
																							1200
																							1300
																							1400
																							1500
																							1600
																							1700
																							1800
																							1900
																							2000
→																							2100
																							2200
																							2300

...ION					10. LEVELS			11. LUBE OIL MAKEUP GALS	
8	9	10	11	12	GOV OIL	CRANK CASE SUMP	FUEL OIL DAY TANK	DRIP OFF	MAG ZEL
40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	41	42
26								3.0	3.0
						TOTAL			
						PREVIOUS			
						TOTAL TO DATE			

...URES				
8	9	10	11	12

12. DIESEL FUEL USED - GAL

☐ METER

METER READING	MULTIPLIER	TOTAL
METER TOTAL YESTERDAY		
NET USED		

☐ SITE GLASS DAY TANK

TOTAL PREVIOUS DAY	
ADDED TODAY	
RUNNING TOTAL	

13. GENERATOR SUMMARY KW - HRS

METER READING	MULTIPLIER	TOTAL
METER TOTAL YESTERDAY		
NET KW - HRS		

GAS USED 1000 CUBIC FEET

METER READING	MULTIPLIER	TOTAL
METER TOTAL YESTERDAY		
NET USED		

19. PLANT STORAGE RECORD (Record on Unit No. 1 Log)

	DIESEL FUEL	LUBE OIL
CARRY FORWARD		
RECEIVED		
SUB TOTAL		
USED TODAY		
ON HAND		

20. STATION BATTERIES

BATTERY CHARGER ON
☐ TRICKLE
☐ CHARGING
________ AMPS
________ VOLTS
HYDROMETER READING
☐ YES ☐ NO
WATER ADDED
☐ YES ☐ NO

18. OPERATING PERSONNEL

SHIFT	FOREMAN
1	
2	
3	
SUPERVISOR	

? CODE FOR TURBO VIBRATION

N - NORMAL   L - LIGHT   S - SEVERE

FOR CHRONOLOGICAL HISTORY USE REVERSE SIDE

PRECEDING PAGE BLANK

DIESEL POWER PLANT OPERATING LOG (DIESEL-ELECTRIC)
(AF 1167 MOD)

COMMAND: ADC BASE: MCCHORD AF BASE SITE: SAGE POWER PLANT DATE 21 APR 75

ENGINE: POS 5 OF 6. ENTERPRISE MODEL DSQ-38, HP-1755, SERIAL NUMBER 57047

GENERATOR, ELLIOT SERIAL NUMBER: 5S-10537 RATING: 1250KW

REVIEWING ENGINEER........................ DATE REVIEWED......................

CHRONOLOGICAL HISTORY & REMARKS

TIME	
0345	FUEL TRUCK ARRIVED, 7500 GALS, CORRECTED TO 7535 PUT INTO TANK #1
0410	ROCKER ARM INSPECTION COMPLETED, ALL NORMAL
0900	FUEL TRUCK ARRIVED, 7500 GALS, CORRECTED TO 7535
1300	ROCKER ARM INSPECTION COMPLETED, ALL NORMAL
1530	CHANGED DROOPS AND LOADED #4 DEG
1545	ROCKER ARM INSPECTION COMPLETED, ALL NORMAL
2030	LOAD BALANCED TO NORMAL

SUMMARY DIESEL FUEL & LUBE OIL USAGE

					PLANT DIESEL	LUBE
METER	658707	DAY TANK PREV	24751			
METER PREV DAY	657249	ADDED TODAY	0			
NET USED	1458	RUNNING TOTAL	24751	CARRY FORWARD	107251	1540
				RECEIVED	15070	0
				SUBTOTAL	122321	1540
				USED TODAY	3286	0
				ON HAND	119035	1540

ENGINE OPER HOURS		ENGINE EXHAUST		STATION BATTERIES	
PREV TOTAL	46943	CLEAR	X	TRICKLE X	1 AMPS
TODAY	24	VISIBLE		CHARGING	122 VOLTS
NET TOTAL	46967	DARK		WATER ADDED	YES
		TIME	900		X NO

OPERATING PERSONNEL

(1)................(2)................(3)................SUPV..............

PRECEDING PAGE BLANK

ENGINE TEMPERATURES

TIME	JKT. IN	H2O OUT	LUBE IN	OIL OUT	TURBO OUT	DAY TANK	CYL #1	CYL #2	CYL #3	CYL #4	CYL #5	CYL #6	CYL #7	CYL #8	FROM TURBO
0	151	156	155	170	160	0.81	660	685	680	640	690	660	670	655	600
100	151	156	155	170	160	0.69	660	685	675	640	690	660	660	655	600
200	151	156	155	170	160	0.94	670	690	675	645	690	660	670	655	605
300	151	157	155	170	160	0.88	670	685	680	640	695	665	675	660	610
400	151	157	155	170	160	0.63	670	680	680	640	690	670	670	660	610
500	152	156	155	170	160	0.88	660	680	670	640	680	660	660	660	600
600	152	156	155	170	160	0.69	640	660	660	625	665	640	670	640	585
700	149	154	155	170	159	0.75	630	660	660	620	660	640	640	640	580
800	151	154	154	170	160	0.75	675	700	695	660	710	685	700	685	640
900	150	161	155	171	162	0.63	710	730	725	695	735	700	710	700	645
1000	150	162	156	171	162	0.81	715	735	725	695	735	705	715	705	645
1100	151	162	155	172	162	0.63	725	745	725	700	740	715	720	705	655
1200	151	162	155	172	162	0.88	720	735	725	695	735	710	720	705	655
1300	151	163	155	172	162	0.63	760*	785*	770*	740	795*	750	765*	745	695
1400	151	161	156	172	163	0.88	700	725	715	680	725	690	700	680	625
1500	151	160	156	172	163	0.69	690	715	715	675	715	685	695	685	625
1600	154	159	153	170	160	0.63	650	680	675	645	680	650	640	635	585
1700	140	140	152	167	152	0.88	490	520	540#	490	525	480	430#	495	450
1800	136	140	152	165	152	0.75	475	500	530	475	510	460	500	470	440*
1900	132	136	152	164	150	0.69	440	465	495	440	475	420	500	450	420*
2000	130	134	151	164	150	0.63	440	470	500	440	475	435	495	450	425*
2100	150	155	155	169	160	0.88	665	685	680	650	675	655	675	660	610
2200	150	156	155	170	160	0.69	670	690	680	650	690	655	670	665	610
2300	149	154	154	170	159	0.63	660	680	680	640	680	650	665	660	600

ENGINE PRESSURES (PSI) / ELECTRIC GENERATOR

TIME	COOL H2O IN	LUBE OIL IN	FUEL OIL IN	TURBO OIL IN	AIR MANI IN	TURBO VIBR	ALT TEMP	AMPS PH#1	AMPS PH#2	AMPS PH#3	KW	KVAR OF PF	EXCITOR AMPS D C
0	13	46	28	37	4.0	NORMAL	60	140			825	88	
100	13	46	28	37	4.0	NORMAL	60	140	140	140	825	88	84
200	13	46	28	37	4.1	NORMAL	60	140			850	88	
300	13	46	28	37	4.2	NORMAL	60	140			850	88	
400	13	46	28	37	4.2	NORMAL	60	140			850	88	
500	13	46	28	36	4.2	NORMAL	58	140			825	88	
600	13	46	28	36	4.0	NORMAL	58	140			825	88	
700	13	46	28	37	4.1	NORMAL	58	130			775	88	
800	13	46	27	36	4.9	NORMAL	57	135			800	85	
900	13	46	27	35	4.5	NORMAL	60	150	150	150	900	69	86
1000	13	46	27	35	4.4	NORMAL	63	150			925	88	
1100	13	46	27	35	4.4	NORMAL	63	150			925	88	
1200	13	46	27	35	4.4	NORMAL	63	150			925	89	
1300	13	46	27	35	4.8	NORMAL	63	150			900	87	
1400	13	46	27	35	4.8	NORMAL	68	165*			1000	88	
1500	13	46	27	35	3.9	NORMAL	63	140			850	88	
1600	13	46	27	35	3.4	NORMAL	63	140			725	88	
1700	12	47	27	36	2.2	NORMAL	53	80	80	80	500	87	71
1800	12	47	27	36	2.2	NORMAL	52	80			450	87	
1900	12	47	27	36	1.9	NORMAL	51	70*			400	88	
2000	12	47	27	36	2.0	NORMAL	50	72*			400	88	
2100	13	45	27	35	4.0	NORMAL	58	130			800	88	
2200	13	45	27	35	3.9	NORMAL	59	130			775	88	
2300	13	45	27	35	3.9	NORMAL	59	130			800	87	

	ENGINE PRESSURES (PSI)							FUEL PUMP RACK POSITIONS							
	FUEL	OIL	LUBE	OIL	CRANK	START	INT	CYL	CYL	CYL	CYL	CYL	CYL	CYL	CYL
TIME	IN	OUT	IN	OUT	VAC	AIR	FIL	#1	#2	#3	#4	#5	#6	#7	#8
100	28	27	56	53	0.4	220	0.5	19.5	20.0	20.0	20.0	20.5	20.0	20.0	19.5
900	27	28	55	52	0.5	210	0.5	21.0	21.0	21.0	21.0	21.5	21.0	21.0	20.5
1700	27	28	58	54	0.5	230	0.4	14.5	14.0	15.0	15.0	15.0	14.5	14.5	14.5

TIME	DRIP OFF	MANZEL
100	1	1
900	1	1
1700	1	1
TOTAL	3	3
PREVIOUS	41	27
TO DATE	44	30

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